

# Response to “Comment on ‘A versatile thermoelectric temperature controller with 10 mK reproducibility and 100 mK absolute accuracy’” [Rev. Sci. Instrum. **80**, 126107 (2009)]

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(Received 10 November 2010; accepted 22 November 2010; published online 10 February 2011)

The preceding comment by Sloman points out that the absolute accuracy of a temperature controller may be compromised by thermistor self-heating. We measured the self-heating of the thermistor used in our temperature controller, verifying a systematic error of nearly 200 mK. However, this error is reduced by over an order of magnitude with a slight change in our original circuit design. With this change, our controller does achieve an absolute temperature accuracy of 100 mK, limited mainly by the stated absolute accuracy of the thermistor used in the circuit. © 2011 American Institute of Physics. [doi:[10.1063/1.3534860](https://doi.org/10.1063/1.3534860)]

In a recent *Note*<sup>1</sup> we described a versatile thermoelectric temperature controller for which we claimed an absolute temperature accuracy of 100 mK, limited mainly by the absolute accuracy of the commercial thermistor used as the temperature-sensing element. Sloman<sup>2</sup> subsequently pointed out that thermistor self-heating may compromise this claim. We measured our thermistor self-heating under typical conditions by passing a known current through a thermistor while monitoring its resistance. During these tests, the thermistor was potted into a temperature-controlled aluminum block using thermally conducting epoxy. We measured a self-heating of  $dT/dP = 75 \pm 5$  mK/mW for thermistor power dissipations in the range  $0 < P < 15$  mW. Since our published circuit<sup>1</sup> dissipates 2.5 mW in the thermistor under typical operating conditions, this translates to a systematic error of nearly 200 mK, which agrees with the analysis of Sloman and is greater than our stated absolute accuracy of 100 mK.

This problem can be remedied by driving the thermistor bridge in Ref. 1 with  $V_0 = 1$  volt instead 10 volts (by switching to a different precision voltage source). This brings the deposited power down by a factor of 100, thus reducing the self-heating to approximately 2 mK. With this lower operating voltage, the effective temperature errors resulting from input

offsets in the buffers and the instrumentation amplifier are increased to approximately 10 mK. With this change, the absolute temperature error in our controller is then mainly limited by the 100 mK accuracy of the thermistor, as desired.

For our controller design under typical operating conditions (as described in Ref. 1), the temperature error from thermistor self-heating is approximately  $dT_{\text{heating}} \approx 2V_0^2$  mK, where  $V_0$  is the bridge voltage in volts. Meanwhile, the effective temperature error resulting from input offsets is approximately  $dT_{\text{offsets}} \approx 10/V_0$  mK, where again  $V_0$  is measured in volts. From this, we see that an optimal bridge voltage of approximately  $V_0 \approx 1 - 2$  volts minimizes the total temperature error.

Sloman also points out that extremely low power dissipation in the thermistor is required for the best possible temperature stability, and stabilities of  $dT < 100$   $\mu$ K have been demonstrated in the literature. As stated in Ref. 1, however, our main goal was not extremely good temperature stability, but rather the best possible absolute temperature accuracy. For the latter goal, relatively larger thermistor power dissipation is optimal.

<sup>1</sup>K. G. Libbrecht and A. W. Libbrecht, *Rev. Sci. Instrum.* **80**, 126107 (2009).

<sup>2</sup>A. W. Sloman, *Rev. Sci. Instrum.* **82**, 027101 (2011).

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